

1 10. SALMONID SPAWNING GRAVEL RESTORATION

1.1 Introduction

1.1.1 Description of Technique

For close to 70 years, rehabilitation and enhancement techniques have been used to mitigate reductions in spawning habitat quantity and quality (Hall and Baker 1982). In the early 1970's, declines in several Pacific salmonid stocks inspired a concerted effort to create new spawning habitat and rehabilitate existing degraded spawning gravels. A variety of means have been employed to address damaged or degraded spawning gravel including cleaning of gravels contaminated with fine sediment and supplementation/replacement of spawning gravels. These techniques and these approaches focus specifically on the gravel component of spawning habitat. Cleaning is an approach that results in a direct creation of habitat. Supplementation is an example of a managed inputs approach to creating habitat. The results from the application of both of these techniques are realized fairly quickly. Other approaches to improving spawning habitat such as the installation of structures are more process based and have a broader focus.

Placeholder for 90%: Other approaches to improving spawning habitat – list them and where to find information on them once the content of the various techniques and techniques names has been fully resolved.

The quantity, quality, and distribution of spawning habitat in a stream system is related to the physical characteristics of the stream channel and watershed. The type and amount of habitat available for spawning varies among stream reaches due to differences in physical characteristics and geomorphic processes among watersheds and stream channels. Factors such as geology (Duncan and Ward, 1985; Crisp and Carling, 1989), sediment supply (Collins and Dunne, 1990; Buffington, 1995), stream power (Benda et al., 1992; Buffington, 1995), and obstructions such as boulders and LWD (Keller and Swanson, 1979; Kondolf et al., 1991; Buffington, 1995) affect the abundance, particle size distribution, and stability of spawning gravel deposits. Hydrology, particularly the flow regime at the time of spawning, affects access to spawning areas, the amount of wetted area, water depth and velocity, and sub-surface flow conditions.

Land-use activities and catastrophic events affect spawning habitat by changing the type or amount of sediment delivered to a stream system or altering patterns of sediment transport and storage within stream channels. Excess sedimentation in streams may occur as a result of chronic soil washing from disturbed surfaces, or more abruptly in mass wasting events such as landslides or debris torrents.

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Removal of forest cover increases both the volume of water that is shed from an area and the rate at which it runs off. Consequently, peak flows in streams adjacent to or downstream of cleared areas tend to be greater, with impacts that include erosion of channel banks and floodplain areas, sedimentation of downstream habitats, and scouring of gravels. Large inputs of fine sediment from logging roads can bury spawning gravel (Platts and Megahan, 1975; Platts et al. 1989). The presence of fines has been shown to be a major cause of mortality during the period from egg deposition to fry emergence. This mortality has been attributed to decreases in the availability of oxygen and in the removal of metabolic wastes (Peters 1962; Turnpenny and Williams 1980) and to entrapment of emerging fry, or alevins (Cooper 1965; Phillips et al. 1975; Hausle and Coble 1976; Platts et al. 1979).

Spawning habitat can be lost or reduced by activities such as bank armoring and stabilization that restrict recruitment of gravel to stream channels, construction of dams that block downstream gravel movement, or gravel mining and stream channelization projects that remove gravel from channels (Collins and Dunne, 1990, Kondolf and Swanson, 1993). Other land use activities, such as the clearing of riparian vegetation, typically result in destabilization of the channel banks, loss of cover, and elimination of the primary source of large woody debris, which in many stream is critical for entrapment of spawning gravels.

Degradation and destruction of spawning habitat is one source of diminished reproductive success in salmonids. The quantity of habitat available within a stream reach for spawning can limit the number of eggs successfully deposited in the gravel, potentially limiting the size of the next generation when spawning habitat is limited (McNeil, 1964; Allen, 1969; McFadden, 1969; Schroeder, 1973; Semenchenko, 1989). Furthermore, the quality of existing spawning habitat directly influences incubation success and fry emergence. Fine sediments that settle out in spawning habitats cause decreased spawning success by filling the interstitial spaces between gravels, thereby "cementing" the substrates and impeding redd construction and fry emergence. Interstitial flow of water may be decreased; leading to depressed dissolved oxygen concentrations for developing eggs and alevins. Infilling of gravels with finer sediment also displaces the habitats of aquatic invertebrates, the primary food sources for salmonids.

1.1.2 Physical and Biological Effects

1.1.2.1 Rehabilitation of Spawning Gravel

Successful gravel cleaning may reduce the amount the fine material in spawning areas, enhance intra-gravel flow (permeability), enhance habitat for aquatic insects, and improve spawning use and reproductive success. Conversely, cleaning of spawning habitat, either mechanically or hydraulically, may temporally destabilize the spawning environment, alter hydraulics desired for spawning, disrupt interstitial environment for aquatic insects, and alter localized sediment transport and deposition

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potentially impacting habitats immediately downstream.

Gravel cleaning can be effective in systems where the cause and source of excessive fines has been controlled or remedied; otherwise it may have only temporary benefit. Stream systems that still entrain and transport excessive fine-grained material, particularly at lower flows, will continue to deposit within spawning gravels. Thus, the physical and biological benefits of gravel cleaning may be only temporary.

1.1.2.2 Replacement / Supplementation of Spawning Gravel

Modifications to channel characteristics by the addition of spawning gravel can have unanticipated effects on banks and adjacent channel segments. These channel modifications may result in changes in the hydraulics and energy of the channel, which control sediment transport by changing flow velocity, scour, and depositional processes. Biologically, the presence of “new” spawning habitat that has not had an opportunity to settle and “season” may attract spawners but actually reduce reproductive success due to initial gravel instability.

1.1.3 *Application of Technique*

The two primary causes of spawning habitat degradation are the accumulation of fine sediments and the scouring / displacement of gravels. Sites that have been degraded by either the accumulation of fine sediment or displacement of spawning gravel, can be improved by cleaning or replacing the gravels. However, the use of these techniques alone is rarely recommended because they will not be maintained by natural processes.

When undertaking a project that creates or enhances spawning habitat, it is crucial to understand the factors and processes that dictate the supply, transport, delivery, and deposition of fine sediment and gravel to the site. One must identify disruptions to the sediment supply and transport processes. Sources of excess fine sediment should be characterized. Similarly, in situations where gravel recruitment is limited, the root cause of this imbalance must be defined. Furthermore, one must understand what is behind the hydraulics that ultimately sort, distribute and deposit gravel into spawning habitat. Site-specific projects are often unsuccessful, or have only limited success, because the designer did not consider, understand, or have a full appreciation of stream processes.

For instance, cleaning of spawning habitat as mitigation for degradation that has occurred in a watershed that has been “clearcut” may prove futile unless a comprehensive investigation of changes in hydrology and sediment production / transport is undertaken. As an example of created habitat, it is critical to ensure that the recruitment of excess fine sediment from upstream be curtailed by slope or channel stabilization, or through changes in land use for a gravel rehabilitation project to be successful beyond

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the short-term. A relatively high degree of success can be achieved in increasing the productive capacity of a stream by stabilization of historically valuable spawning habitat and by reducing sediment transport from degraded hill slides to spawning areas.

Similarly, before adding gravel to a degraded stream, one should consider why there is no suitable gravel there to begin with. Is it due to a lack of supply / recruitment (e.g., the presence of a dam upstream or bank protection) or due to transport conditions in the stream channel that limit gravel deposition? As an example of a managed inputs approach to creating habitat, supplementation acknowledges the sediment imbalance, and works with intact processes to create suitable habitat conditions. However, in some situations, such as high gradient sections of the channel, spawning substrate may never collect naturally. Adding “spawning sized” material to a channel in which the shear stresses are too high to retain the gravel is a waste of effort and money. Projects relying on gravel supplementation can appear successful immediately after construction only to be destroyed after a high-flow event. Placement of gravel at these sites may lure salmonids to spawn there only to have their eggs and the gravel washed out during periods of high flow. For these reasons, spawning habitat placement as a mitigation or enhancement technique has only very specific application and should be done only with a clear understanding of the physical processes involved and the biological needs of the fish.

1.1.3.1 Rehabilitation of Spawning Gravel

A variety of techniques have been used to rehabilitate degraded spawning habitat. The focus of these efforts has been: 1) the removal of fine material, “fines”, from the spawning bed, and 2) providing access to spawning gravels that have become armored. Typically, gravel-cleaning techniques are useful only when a streambed has been adversely impacted by a single event or by a situation that has been corrected so recontamination won’t occur. Rivers and streams with chronic, non-point-source pollution are not good candidates for gravel cleaning. Ideally, land use measures and restoration techniques should be employed that address the source of the problem (e.g., reduce delivery of fines to stream on a watershed scale or restore roughness to the channel to naturally clean and sort gravels).

1.1.3.2 Replacement / Supplementation of Spawning Gravel

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Spawning gravel supplementation describes a technique whereby gravel is added to a system in order to compensate for an identified loss or reduction in gravel supply. Supplementation is usually undertaken in situations where recruitment of gravel is limited, and a shortage of spawning habitat has been documented. Examples include channels affected by upstream reservoirs and urbanized streams that have been armored extensively. It is the only measure that can compensate for the loss of a gravel source. Gravel supplementation relies on hydraulic processes within the stream to distribute the material throughout the downstream reach over time. As such, the mechanisms of gravel and sediment transport in the watershed must be understood for a project like this to be successful. Maintenance will involve periodic gravel additions until the natural source is restored.

Gravel supplementation efforts generally require a large amount of material. Spawning gravel may be added to a channel in a variety of ways, including using a helicopter, conveyor belt, tracked excavator, dump truck, or even by hand carried bucket. Gravel should be placed at locations within the channel prone to erosion and scour such as along point bars, stream banks and the upstream end of mid-channel bars.

Note: Canadians have done this a number of times—get information from them and the literature on where and how to place material.

1.2 Scale

Gravel cleaning is generally conducted at a specific site to correct and enhance localized conditions. Large-scale gravel cleaning operations are rarely conducted, and indeed are probably not appropriate. System-wide siltation of spawning gravels will be better corrected through process-based approaches, primarily controlling sediment sources.

Conversely, gravel supplementation is generally not effective at the site-specific scale. Typically supplementation is conducted in a manner that integrates sediment entrainment and transport processes for a larger-scale effect.

Placeholder: include a sample or two of the actual volumes of material that have been used on these projects.

Placeholder: discuss relative sizes of streams and rivers in which both techniques may be relevant or practical. Define in terms of order number of streams/rivers.

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1.3 Risk and Uncertainty

1.3.1 Risk to Habitat

1.3.1.1 Gravel Cleaning

Gravel cleaning operations are inherently intrusive. The majority of techniques employed to clean gravel involve the use of heavy equipment to physically disturb the degraded environment. Immediate direct impacts include the disturbance of aquatic insect habitat and the downstream release of fine sediments. Less immediate impacts relate to the instability of the altered environment. Until the cleaned environment settles and “stabilizes”, eggs that are deposited during spawning may be prone to destruction if the gravel bed shifts.

1.3.1.2 Gravel Supplementation

The selection of material size and volume is critical to minimizing risk to habitat. Newly placed spawning habitat is attractive to fish as perceived spawning habitat. If material is not properly placed or has not had time to settle, however, it can shift or even wash away after the fish have spawned, causing destruction of incubating eggs. Improperly sized gravels (gravels too small to remain naturally stable in the stream) may also flush out, filling downstream habitats.

1.3.2 Risk to Infrastructure

Spawning-habitat enhancement poses minimal risk to existing infrastructure. The greatest risk to infrastructure is the possibility of aggradation resulting from gravel supplementation. If excessive gravel is added, or becomes entrained, it may accumulate in unwanted areas, for example upstream of a culvert, causing risk to the performance of the culvert. Gravel cleaning poses no risk to infrastructure.

1.3.3 Uncertainty in Technique

There is a high degree of uncertainty in both gravel cleaning and supplementation techniques. The success of both is highly dependent on the hydrologic and sediment transport regimes of the particular stream. Additionally, salmonids’ spawning needs are highly particular, species specific, and seasonal. The creation of desirable spawning habitat for adults is in vain if conditions during egg incubation are unstable. Reliability and success is greatly increased when the finished project allows for natural channel process and gravel mobility to occur. Results from gravel cleaning studies are variable. Studies indicate that while cleaning may result in improvement of the spawning environment, this does not guarantee increased use or improved reproductive success. Managed inputs (gravel supplementation) have a high uncertainty of success—success and longevity of results is dependent on high flow events

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that are somewhat unpredictable.

1.4 Data Collection and Assessment

Data collection and assessment needs are variable and contingent on the intent of the project, the nature of the channel, and the modifications to be implemented. Data collection and assessment must allow for careful consideration and analysis of the full range of potential impacts and effects. Field data collection should include the following at a minimum:

- Documentation of site constraints and project limits
- Documentation and mapping of existing habitat features
- Evaluation of existing habitat value and a biological assessment (e.g., pre-project egg to fry survival and valuation)
- Photo documentation of site from permanent benchmarks that will not be disturbed by the project
- Additional data necessary for baseline monitoring (specific data required is dependent on monitoring objectives)

Characterization of hydrologic, hydraulic, and sediment transport conditions should include:

- Characterization of bed materials and of sediment sources, both gravel for spawning, and fine-grained which affects spawning
- Determination of channel forming discharge and flood discharges
- Flood and overbank flow profiles of existing hydrologic conditions
- Volume and gradation of sediment supply
- Hydraulics; including velocity, shear, and scour along the channel
- Characterization of sediment transport dynamics

For further discussion of the methods of sediment transport analysis and hydraulic analysis, and for the data needed for these, refer to the Hydraulics and Sediment Transport appendices.

1.5 Methods and Design

Streambed composition at any site is a function of local and regional factors, including geologic, geomorphic, hydrologic, and hydraulic parameters. While spawning habitat exists naturally, these factors work in concert to provide a supply of gravels and conditions that maintain both the quantity and quality of those gravels. Where degradation of spawning habitat has occurred, the primary objective is to re-establish the conditions that provide for ideal spawning habitat. Typically, it will be necessary to precede instream restoration works with restoration or land use changes that minimize fine-grained sediment and provide for natural supply of spawning-sized gravels. This may include hillslope restoration or stream bank stabilization techniques.

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Potential rehabilitation sites must be assessed carefully by appropriately skilled personnel, as improperly designed or constructed works will typically fail and result in further degradation of habitat. Situations that should be avoided include channels that are laterally or vertically unstable, streams that carry large volumes of bedload, and streams with steep gradients (over 2 – 4%). Factors that must be considered in site selection and design of spawning habitat improvement projects include stability and size of material used, structural durability, and stream characteristics (bed and bank stability, sediment load, gradient, and discharge regime). Ideally, any rehabilitation of spawning areas would be located in areas of natural upwelling, which are typically dictated by variations in streambed elevation. Methods for improving the quality and quantity of existing spawning habitats, and the creation of additional spawning habitat are described below.

1.5.1 Rehabilitation of Spawning Gravel

Gravel cleaning strategies have centered on the separation of fines from the streambed by disturbing the spawning bed to allow the stream's flow to wash fines from gravel. This is accomplished by sifting fines from the spawning bed mechanically, or by flushing fines from spawning beds with hydraulic force, so that they can be washed downstream by flow or removed from the stream with a suction device.

1.5.1.1 Mechanical Removal of Fines

Cleaning of spawning gravels has usually been conducted on a relatively small scale in discrete reaches of a river. The simpler methods of mechanically removing fines from spawning gravels used in the past involved the use of heavy equipment such as a bulldozer, backhoe, or front-end loader to physically disturb the substrate. Perhaps the most common method of cleaning gravels involves the use of a bulldozer (Hall and Baker 1982). The bulldozer moves up and across the stream at a 45 degree angle to the flow, angling its blade like a plow, so that gravels are turned to a depth of 10-14 inches and pushed up in the flow of the river where fines can be washed downstream. After each pass, the bulldozer recrosses the river downstream and begins a new pass 6-7 feet downstream of the last pass. In this manner, the potential of recontamination of cleaned gravels by suspended fines is minimized.

R. J. Gerke³ supervised the successful use of a bulldozer in cleaning spawning beds in several Washington rivers that have suffered from heavy siltation caused by landslides. On the Cedar River, 29,000 square meters of gravels were cleaned using a bulldozer. About 3,000 sockeye salmon and 50 chinook salmon spawned following the cleaning operation. A section of the Entiat River in Washington was also successfully cleaned using a bulldozer, according to D. A. Wilson.⁴ J. R. West reported that spawning by chinook salmon increased in Scott River in Northern California after gravels were cleaned there with a bulldozer.⁵

Another method of cleaning gravel by tilling them, and thereby washing them with the stream's flow,

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involves the use of a 5-foot wide digging bucket mounted on a G-600 Gradall. Moving downstream, the Gradall excavates the gravel to a depth of 1-2 feet. The excavated gravel is then slowly poured back into the stream bed, allowing the stream to wash away the fines. Tests on the Nadina River by Andrew (1981) resulted in a reduction in the percentage of material less than 0.5 mm from 44 percent to 32 percent, and complete removal of fines 0.3 mm and smaller. Cleaned areas also showed significant increase in permeability. However, subsequent spawners did not utilize the cleaned areas. Similar cleaning carried out on the Horsefly River was followed by heavy use by spawners, but there was no improvement in gravel permeability or egg survival to emergence.

In an attempt to minimize the release of fines into the stream flow, the International Pacific Salmon Fisheries Commission used a Gradall carrying a modified 7-foot digging bucket with a screened bottom constructed of 1/8-inch wire mesh, capable of separating fines from the gravel bed within the stream channel (Mih 1978). The machine works downstream, scooping up gravel to a depth of about two feet and hydraulically vibrating the bucket in the water so that fines within the gravel come out the screened bottom of the bucket and are deposited into the hole just created. When this has been accomplished, the cleaned gravel in the bucket is returned to the hole and the machine moves to the next spot to be cleaned. The resulting gravel bed is freed of fines for approximately the first 12 inches, under which there is a layer rich in fine sediments. It is not clear if such stratification of the gravel bed could be detrimental to spawning success.

Mechanical methods are most successful at reducing fine-sediment concentrations if conducted during relatively high stream flows. However, due to Endangered Species concerns associated with the presence of equipment in the stream and the release of sediment and potential for contamination of other spawning habitat downstream, this method will have limited opportunity for application.

1.5.1.2 Hydraulic Removal of Fines

Another approach to the cleaning of spawning gravels incorporates the use of a hydraulic flushing action to mobilize and collect fine sediments. The "Riffle Sifter," developed in 1963 by the U.S. Forest Service, was the first machine designed to hydraulically remove fines from choked spawning areas. The Riffle Sifter flushes fine sediments from the substrate by injecting a high-speed jet of water into the streambed through a series of pipes. The apparatus then collects the fine sediments through a suction system and jets them onto the floodplain. The Riffle Sifter has been shown to remove up to 65 percent of the particles smaller than 0.4 mm.⁶ However, previous application has been subject to mechanical problems in the course of cleaning in natural streambeds.⁷

A prototype gravel cleaning machine called "Gravel Gertie" was developed by a professor at Washington State University in 1979 for the Washington Department of Fisheries as a more advanced version of a hydraulic gravel cleaning machine.⁸ The Gravel Gertie is mounted on a low-bearing

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pressure tracked vehicle that drives through the riffle during operation. The hydraulic cleaning action of Gravel Gertie uses a vertical jet of water, which is directed towards the streambed to flush out fine sediments. A suction system within a rectangular collection hood removes fines from stream flow. Gravel Gertie was field tested on the Palouse River in northern Idaho and on Kennedy Creek and several other streams in Western Washington. Effective cleaning was accomplished to substrate depths of 12 inches. All of these streams showed a decrease in the percentage of fines after one pass, with reduction of fine sediments (<0.0841 mm) ranging from 3 to 78 percent.

On a smaller scale, Mundie and Mounce (1978) described the successful use of a small pump and firehose in cleaning gravels in a small channel. However, the potential for uneven cleaning is greater with this technique compared to the larger scale approaches.

Gravel cleaning projects should be initiated at the upstream limit of spawning areas and proceed downstream.

1.5.2 Replacement / Supplementation of Spawning Gravel

The production, transport, and deposition of sediment are key elements in understanding gravel supply in a stream system (Anderson, 1971; Collins and Dunne, 1990). The quantity, particle size composition and distribution of gravel deposits throughout a stream system are determined by factors affecting sediment supply to the channel, such as the amount, type, timing and location of sediment inputs (Collins and Dunne, 1990), and factors affecting sediment transport and deposition within the channel, such as discharge, gradient, depth, of flow, obstructions and channel morphology. Gravel supplementation can provide a means of compensating for a lost or reduced supply of gravel. In reaches that are limited in gravel recruitment either because of an upstream impoundment or armored banks, a streambank or a gravel bar can be constructed of gravel and designed to erode providing a source of spawning gravel to downstream reaches over time. This technique relies on high flows to distribute the gravels and as such gravel must be sized based on sediment transport calculations and project objectives.

Placement of gravel should be limited to extended stable reaches that lack a natural source of gravel and display characteristics that are conducive to gravel retention such as large woody debris and complex bedform and planform. The greatest success has generally been achieved at sites downstream of lakes and reservoirs, and at groundwater-fed channels, where streamflow is relatively stable. In other stream settings it may be necessary to install instream structures to prevent the downstream transport of the placed gravels. For further discussion of instream structures that trap gravels, refer to Debris Jams technique.

Sizing of material should be first determined by the hydraulic characteristics of the site and secondarily by its spawning characteristics. If hydraulic characteristics of sediment transport are not conducive to

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the entrainment and deposition of spawning sized gravels, then the stream is not an appropriate candidate for gravel supplementation technique. Gravel should be sized to become mobile at the bankfull flow event. This can be accomplished using tractive force computations. Refer to the Sediment Transport Appendix for a complete discussion of tractive force and other sediment transport analyses. It may be most practical to use a gradation of gravels with a range of sizes, either due to the practicality of supply availability or to accommodate multiple species requirements. If a gradation of gravel sizes is used, the D50 of the gradation should be sized for incipient motion at the bankfull discharge.

Placeholder: discuss how to determine how much gravel to add and how often. Note that this technique relies predominantly on natural process to transport, deposit and sort gravels appropriately, and therefore methods need to focus on identifying where this might be, and place gravel in proximity to this.

Placeholder: discussion of where to place gravel should include options for in-channel or on bank, in addition to consideration of proximity to spawning sites.

1.5.2.1 Spawning Habitat Characteristics

The characteristics of actual spawning sites vary extensively between species and among stocks of the same species (Table). Factors such as substrate size, water depth, and water velocity appear to limit where a female is physically able to construct a redd. Body size and stamina determine the size of particles that can be moved, the ability to work in fast water, and maneuverability in shallow water. If there is extensive variation in the size of individual members of a population, differences in velocity, minimum depth, and substrate preferences may be nearly as great between members of the populations as between different stocks or species (Hunter, 1973). Studies indicate that there is a relatively wide range of acceptable conditions for most species (Hunter, 1973).

Table X. Water depth, velocity, substrate size, and area required for spawning criteria for some salmonids (Slaney and Zoldokas 1997).

Species	Minimum Depth (m)	Velocity (m*sec ⁻¹)	Substrate Size Range (mm)	Mean Redd Area (m ²)	Req'd Area per Spawning Pair (m ²)
Fall chinook salmon	0.24	0.30 – 0.91	13 – 102	5.1	20.1
Spring chinook salmon	0.24	0.30 – 0.91	13 – 102	3.3	13.4
Summer chinook salmon	0.30	0.32 – 1.09	13 – 102	5.1	20.1
Chum salmon	0.18	0.46 – 1.01	13 – 102	2.3	9.2

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Coho salmon	0.18	0.30 – 0.91	13 – 102	2.8	11.7
Pink salmon	0.15	0.21 – 1.01	13 – 102	0.6	0.6
Sockeye salmon	0.15	0.21 – 1.07	13 – 102	1.8	6.7
Kokanee	0.06	0.15 – 0.91	13 – 102	0.3	0.15
Steelhead	0.24	0.40 – 0.91	6 – 102	4.4 – 5.4	
Rainbow trout	0.18	0.48 – 0.91	6- 52	0.2	
Cutthroat trout	0.06	0.11 – 0.72	6 – 102	0.09 – 0.9	

Substrates used to supplement spawning gravel should be consistent with the optimal substrate size and composition for the target species (Table Y). For most species of salmonids, the general guideline is approximately 80% of 10 to 50 mm gravel with the remaining 20% made up of 100 mm gravel and a small portion of coarse sand (2 to 5 mm). More specific substrate mixes can be tailored to fish size. Small-bodied salmonids¹ spawn in gravel that is generally between 8 mm and 64 mm in size. Large bodied salmonids² spawn in gravel that is generally between 8 mm and 128 mm in size.

Table Y. Average size composition of gravel in redds of three Pacific salmon species (Adapted from Andrew and Geen, 1960 and Burner, 1951). Approximate average weight of each species shown in brackets.

Gravel Size (diameter)	Fall-run Chinook (9 kg)	Coho (4 kg)	Sockeye (1.5 kg)
	Percent		
Fines	10	8	12
3 – 12 mm	19	23	23
13 – 50 mm	38	43	51
51 – 100 mm	21	23	12
101 – 150 mm	12	3	2

1.6 Project Implementation

1.6.1 Permitting

Permitting channel modification projects will be very site- and project-specific. Channel modification

¹ Small-bodied salmonids are defined as species that are typically less than 35 cm long when mature, including resident rainbow, resident cutthroat, anadromous cutthroat, bull trout (dolly varden), brown trout, brook trout, and kokanee.

² Large-bodied salmonids are defined as species that are typically greater than 35 cm when mature, including pink, chum, coho, sockeye, steelhead, and chinook salmon.

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invariably involves physical disturbance of the channel, which disrupts habitat and water quality at the site and downstream. A general discussion of permitting requirements is included in Chapter 4.6 of this document.

1.6.2 Construction

A general discussion of construction issues and considerations is provided in the Construction Appendix.

Placeholder: bulleted list of construction considerations specific to this technique that are detailed in the appendix.

- *Access to the channel for material and equipment delivery*
- *Construction timing*
- *Equipment selection for delivering material to or working in remote sites*

1.6.3 Materials Required

The selection of appropriately sized spawning gravels is critical to the success of the project. Sizing of material should be first determined by hydraulic characteristics and then by spawning characteristics. The intent is to provide a stable mix that includes “spawning-sized material”. Angular or crushed gravels should not be used as spawning substrate. Refer to the Sediment Transport and Hydraulics Appendix for further information on sediment transport. Specific mixes vary for sizes and species of fish and hydraulic conditions. In some applications, it may be appropriate to augment spawning gravels with larger materials to add initial stability especially when the material is expected to be naturally sorted such as in higher gradient reaches and when creating spawning habitats that have lengths and widths similar to the full channel width.

1.6.4 Timing Considerations

Because both gravel cleaning and gravel supplementation require primarily in-channel work (cleaning or depositing gravel), the primary timing consideration will be potential disturbance of spawning and rearing activity within the channel. Construction timing should avoid critical periods in salmonid life history such as spawning, migration and egg incubation. In-stream work windows vary among fish species and streams. Contact the Washington Department of Fish and Wildlife's Area Habitat Biologist for information on work windows (see Appendix 2, Washington Department of Fish and Wildlife Regional Offices). Further discussion of construction timing and dewatering can also be found in the Construction Considerations appendix.

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1.6.5 Cost Estimation

Cost is highly variable in spawning enhancement projects. For supplementation projects, availability and delivery of materials contribute to variability in costs. A cost-saving option used by the Washington Department of Fish and Wildlife to obtain spawning substrate is to mine and sort gravels near the site. This technique involves the use of a mobile sorting operation positioned near the project site. Delivery costs are significantly reduced using this method. Sorted gravels may cost \$20 to \$40 per cubic yard. Dewatering of a project site can add significant cost to a project. Dewatering costs are greatly affected by the size of the channel and other site-specific factors.

Table Approximate costs for selected spawning habitat rehabilitation projects (from Slaney and Zaldokas 1997).

Project Type	Approximate Costs	Comments / Assumptions
Gravel cleaning – mechanical scarification	\$5-20 per m ²	Bulldozer working instream Streams over 10m wide
Gravel cleaning – manual	\$20-50 per m ²	High pressure hose Small, shallow streams
Gravel placement	\$50-70 per m ³ gravel	Sorted gravel supplied Limited delivery distance Machine placed Does not include control structures

1.6.6 Monitoring and Tracking

Biological monitoring provides the ultimate measures of project success. Annual spawner counts and redd surveys are the most direct measure of spawning utilization but not necessarily success, i.e., egg to fry survival. Other measures (redd capping, fry trapping, seining, snorkeling) can provide information on incubation success.

In addition to biological monitoring, monitoring the physical conditions is important to document project performance. Measurements of the degree of scour, distribution and abundance of gravel, gravel sorting, channel movement, and the condition of retention structures are recommended elements of a monitoring plan. Constructed spawning habitat, including bed forms and woody debris, may be carefully surveyed immediately after construction and again after initial high flows to document changes that might affect spawning success. Spawning chains or other devices intended for measurement of spawning-gravel stability and scour can also be used. However, it is very difficult to quantify impacts of bed instability near hydraulic structures, since the hydraulics will be quite varied around the structure.

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For a comprehensive review of habitat monitoring protocols, refer to the Washington Department of Fish and Wildlife work in progress, *Inventory and Monitoring of Salmon Habitat in the Pacific Northwest*.¹⁰ Monitoring the project for its integrity as a spawning site will likely require a more comprehensive schedule than that required for the integrity of the structures.

Monitoring of physical characteristics and biological use should be conducted annually for both gravel cleaning and supplementation projects.

1.6.7 Contracting Considerations

1.7 Operations and Maintenance

Gravel cleaning is typically applied to remedy a localized site problem and is not to be applied to treat chronic watershed problems. As such it is not intended to be a repeated measure.

Gravel supplementation projects must be monitored regularly and periodically supplied with additional gravel.

1.8 Examples

Gravel Supplementation

Sacramento River, Redding CA.

Examples in BC as well

Gravel Cleaning, LWD Installation...

1.9 References

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1.10 Photo and Drawing File Names

No photos yet – suggest Hurd Creek